Good morning/afternoon, Ladies and Gentlemen, I would like to talk to you today about a few of the challenges that we face in designing microsystems that integrate a number of different technologies.

These comments are true for a number of different technology areas. If we were to look at engineering systems today, it is quite obvious that levels of integration are increasing; we see more of multi- scale, multi-disciplinary phenomena that interact in complex and highly non-linear ways; and we see components of different materials (i.e., properties) and technologies being integrated into the same platform.

What this essentially means is that system COMPLEXITY is increasing; it is harder for us to understand system behavior and be able to predict system performance over a range of operating conditions. Intuition and experience (which have worked for us in the past) are failing us when it comes to designing systems with such complexity.

It is not surprising therefore, that design costs for mixed technology systems are increasing exponentially. What is needed in the future are physics-based simulation tools that can accommodate the complexity of the system and predict its behavior/performance accurately.

This will give us the opportunity to optimize the design before the physical prototyping is done.

If one were to look at the design of mixed technology systems today, but for a few exceptions, the design process is based on a bottom-up approach. Design simulations are done in an ad-hoc manner without the use of a consistent methodology.

Future systems should be designed from the top-down using a consistent set of requirements.

With this methodology comes predefined decisions and imposed restrictions that save time and effort, prevent design problems and produce designs that are "correct by construction." This is the basis of design automation. One industry that has benefited significantly from design automation is the Integrated Circuit industry.

It is an uncontested fact that Electronic Design Automation tools have played a significant role in the development of each successive generation of high-density chips.

However, integrated microsystems of today are much more complex than Integrated Circuits.

We are no longer looking at just the flow of electrons. We have chips that integrate a number of different technologies - electronics, optics, MEMS, fluidics, chemistry, biology, to name a few; this results in a multiple-input, multiple-output system with a high degree of non-linear interactions. The question is -- Can we extend the VLSI design philosophy to such complex microsystems?

As an example, let us consider a typical bio-chip (or a bio-microdevice) for a sensor application.

We have a microfluidic system for collecting, preparing and transporting fluid samples.

The detection process involves molecular recognition and the conversion (or transduction) of this signal into a measurable electrical, mechanical or optical signal.

The operation of the bio-chip requires the interaction between several disciplines such as fluidics, mechanics, electromagnetics, materials science and bio-chemistry. It is extremely difficult (if not impossible) to optimize these interactions without the use of CAD tools.

I want to show you some of the typical molecular recognition processes that are used in sensors today. Antigen-antibody binding, DNA hybridization, enzyme-substrate reaction are typical examples of such processes. It is obvious that these processes involve highly complex, non-linear interactions at the molecular scale.

We need advanced models to obtain a quantitative description of these phenomena.

Signal transduction is an important part of the detection process. In one sense, it is where the biology meets the engineering.

Shown here are typical examples of transduction of the molecular recognition signal to mechanical and electrical signals. It is important to keep in mind that the transduction process has to serve two objectives; firstly it should detect the presence of the target molecule in the sample; secondly it should estimate the concentration of the target molecule in the sample from the intensity of the transduced signal. Again, advanced models are required to understand the scaling of these processes.

Microfluidic and molecular transport are absolutely critical in transporting the target molecules to the detector. Multi-disciplinary interactions and the multi-scale nature of the process make it extremely difficult to optimize the transport.

The availability of computational models will enable the design of high performance, high-efficiency microfluidic systems.

Other examples of mixed technology microsystems include mixed signal (digital- analog) systems and mixed electronic-photonic systems.

These systems are finding important applications for the DoD in the areas of sensing and communication. The typical design cycle times for these complex systems are on the order of years; the current design methodologies lack automation, they are based on ad-hoc approaches requiring considerable skill and experience.

We need design automation for these applications.

In order to implement a top down system design approach, we need to have reduced order models and behavioral models for each of the components and elements of the system.

We need fast solvers at the level of 3-D modeling that reduce computing times by orders of magnitude, we need new methods to perform model abstraction that result in reduced order and behavioral models. We are doing this now for linear systems.

However, there are many challenges to be overcome in extending this approach to non-linear systems.

As I mentioned just now, we have begun to address the design of integrated Microsystems.

There are many design success stories emerging from ongoing efforts. CAD tools are starting to make an impact in the MEMS industry by enabling better designs and higher yields.

Electro-fluidic design tools are also becoming available to the microfluidic community.

New processes (with better uniformity) are being designed using these tools. The models are also transitioning from being 'analysis' tools to "predictive" tools thus enabling significant reduction in design cycle time and cost.

Also resulting from ongoing efforts are system level tools consisting of abstracted models of devices. Abstracted or behavior models of devices and sub-systems enable quick analysis of complex systems consisting of several components. This is an important part of the top-down design approach.

Therefore, in summary, the focus areas for the future are to firstly, (i) enable quantitative modeling of individual devices such as microfluidic elements, MEMScomponents and photonic devices, and to secondly, (ii) enable model abstraction of these components thus facilitating system level analysis of integrated microsystems. The question is-- What will this buy us ??

This will buy us the capability to design microsystems with a high level of multi- disciplinary integration.

I believe this is one of the key enablers for achieving (a Moore's Law type of) exponential growth in the technology areas under consideration.

Please feel free to approach me during the next couple of days to discuss your ideas and suggestions for helping us address these challenges.

I look forward to talking to many of you. Thank you for your attention.